II. "On the Mechanical Conditions of the Respiratory Movements in Man." By Arthur Ransome. Communicated by Dr. Sanderson, F.R.S. Received June 22, 1872.

(Abstract.)

The importance of an accurate measurement of the respiratory movements has been recognized by numerous physicians, and many different methods have already been in use for this purpose; these methods, however, have hitherto only given either simply the gross enlargement of the circumference of the chest, or the resultants of the motions of the different points on the chest-wall. Now, owing to the shape and mode of articulation of the ribs, the movements of any point on either side of the sternum may take place in three planes at right angles to one another, and need each to be recorded separately; and, owing to the variations in healthy breathing, it is further important that all these movements should be measured during one act of breathing.

The stethometer used in the following inquiry accomplished all these tasks, and measured simultaneously the three dimensions of movement of any point on the chest-wall. Graphic representations of these dimensions could also be obtained.

It was necessary to observe forced breathing chiefly; and it was noticed that when the button of the instrument was applied either to the middle of the sternum or on the end of one of the sternal ribs, the chief motions were forward and upward; that the forward motion was most equable, and started much more rapidly at first than the upward movement.

The earliest portion of the expansive act seems to be accomplished by an increase of the ordinary action of the diaphragm; then the chest gradually swells outwards and forwards, the ribs are raised, commencing usually at the lower ribs, the costal cartilages are straightened out, the head and shoulders are fixed, and the spinal column is curved backwards. In expiration after this effort the operation is reversed: variations in this action may be brought about by disturbing emotions, habit, suggestions from others, or antecedent ideas. Possibly, in consequence of this fact, the above account differs from that given by Haller, Sabatier, Majendie, Hutchinson, Sibson, and others. Care was therefore taken to ascertain its correctness, and it was tested,—1, by fastening tapes of paper round the chest, and noticing the order in which they were torn on deep inspiration; 2, by simultaneous tracings of the action of the 2nd and 5th or 6th ribs made, by means of Dr. Burdon Sanderson's stetho-cardiograph, on both males and females. The curves so produced were then carefully examined, and conclusions drawn from them as to the differences between male and female respiratory movements. In the Tables giving the dimensions of the motions of different points on the chest in healthy adult males, amongst other facts certain cases were noticed in which the parallelism of the movements of the sternum was interfered

with. Traube's observation as to the influence of the diaphragm on the lower end of the bone was confirmed. The clavicles were shown to have more upward than forward motion, and to move less than either sternum or ribs.

The ribs move upward more decidedly than the sternum, their rotation outwards permitting greater freedom. Their forward push is very considerable, greater than that of the sternum, often equalling or exceeding their upward rise. The upper ribs have sometimes greater forward thrust than the lower; there is no regular series in this respect in the different ribs, but, on the contrary, much evidence of the independent action of the several ribs.

The greatest amount of outward motion takes place on the rib about midway between the vertebral column and the sternum.

The measurements obtained by means of the stethometer show:—

1. That the upward dimensions of the movement are sufficiently accounted for by the upward rise of the ribs, their chord-length being taken as radius, their vertebral attachments as centres.

It may be shown also mathematically that the curving of the dorsal and lumbar regions of the spine in natural respiration would usually interfere but slightly with this "upward" reading.

2. The outward indications are also probably to be accounted for by the simple radial rise of the costal ends of the costal cartilages, the sternal articulation being taken as centre.

3. The "forward" movement is, however, much more complex. It could not arise from any simple alteration in the obliquity of the ribs:—

a. Because there is no constant relation to be discovered between the amounts of "forward" and of upward movement; and it is possible, voluntarily, at one time to produce an excess of forward, at another of upward motion.

b. Because the angles made by the ribs with the spine are not such as to permit of the amount of forward movement recorded by the stethometer. This fact is proved by measurements of these angles as found in anatomical drawings, in skeletons, and in the living subject.

In the latter the amount of forward push not accounted for by the simple rise of the rib was found to be often as great as 0·5 in. for the fifth rib, and 0·7 in. for the third rib. One example out of many of these cases is here given.

Case.—Male, æt. 32. Strong, healthy; 6 feet in height.

Gross diameter over 3rd rib	$8\frac{1}{2}$ in.
Gross diameter over 5th rib	$9\frac{1}{2}$ in.
Estimated chord-length of the 3rd rib 6·75 in., of 5th rib ..	7·65 in.
Angle formed by the right 3rd rib during expiration	63°
Angle formed by the right 5th rib during expiration	61°
Inspiratory angle of the right 3rd rib	78°
Inspiratory angle of the right 5th rib	75°

	Forward.	Upward.
Calculated motion of the end of the 3rd rib	61	160
Calculated motion of the end of the 5th rib	53	140

Motion of the Ribs as observed with Stethometer.

A, when the whole back was supported	3rd rib ..	135	160
	5th rib ..	115	120
B, when the 3rd and 5th vertebræ alone were supported	3rd rib ..	135	160
	5th rib ..	115	120

Extent of forward push of 3rd rib not accounted for...... 0·74 in.
Extent of forward push of 5th rib not accounted for...... 0·62

4. The excess of forward motion is found not to be explained (*a*) by the *genou*-lever action of the costal cartilages with the ribs, (*b*) by the curvature of the spine, (*c*) by the backward thrust of the angles of the ribs.

5. It may be concluded, therefore, that the mechanical conditions of the thoracic machinery would prevent any forward motion to the extent observed, unless it was possible for the ribs themselves either to be inbent or straightened out.

6. It may be proved that the ribs are *capable* of being bent (*a*) by experiments upon freshly separated ribs, (*b*) upon dead subjects, (*c*) upon living subjects, (*d*) by pathological facts.

7. The means by which an alteration in the chord-lengths of the ribs could be brought about may be discovered in several directions, especially in the intrinsic thoracic muscles.

8. It may be shown that the hypothesis of either the straightening of the ribs in inspiration, or their previous inbending in expiration, (*a*) accounts for the extent of the forward indications of the stethometer, (*b*) their varying amount in the same individual in relation to the upward motion, (*c*) for the extraordinary extent of these forward indications in women and young children as compared with those of strong men and old people; (*d*) it explains the comparatively large extent of forward movement of the upper as compared with the lower ribs; (*e*) it is supported by the peculiar stethometric measurements obtained in various diseases of the lungs; (*f*) by the fact that the excess of forward movement is found to increase from the middle to the anterior end of the rib.

On the Respiratory Motive Powers.—By what means may the inbending or straightening of the ribs be accomplished?

That the forces concerned in respiration are sufficiently powerful is proved by several considerations, notably by Hutchinson and Haughton's calculations of muscular power.

The purely mechanical forces are probably not often brought into action. The effect of the extraordinary or external muscles of respira-

tion was not examined by means of the stethometer; but from Mr. Le Gros Clark's experiments it would appear that they have but little influence in forced inspiration.

With the intrinsic thoracic muscles the case is different. It is probable that, with the exception of the *levatores costarum*, each of these muscles has some further power beyond that of simply raising or depressing the ribs.

The *triangularis sterni* is more especially a constrictor of the anterior part of the thorax.

The *intercostals* have very various actions assigned to them; but when all the evidence of Traube, Sibson, and others is considered, it seems most probable that the six upper ribs are raised by the external intercostals, and depressed by the internal muscles; but the ribs are not rigid bars, and hence these muscles have a further action upon them. From careful experiments upon a model with elastic vulcanite ribs, and elastic bands stretched between them in the direction of (*a*) the external intercostals, (*b*) the internal intercostals, and (*c*) with now the upper ribs fixed, now the lower, it was concluded that whilst modifications were introduced into their action by the last-named condition, yet that without doubt the tendency of the external intercostals was, 1st, to draw the ribs upwards; 2nd, to separate their anterior ends; 3rd, to straighten them. On the other hand, the action of the internal intercostals was, 1st, to draw the ribs downwards; 2nd, to bring their anterior extremities nearer together; 3rd, to bend them inwards. These results were explained by resolving the forces of these muscles in the directions (*a*) along the ribs, (*b*) at right angles to them.

The diaphragm may also be considered to have an important action in bending the lower ribs.

Evidence can be adduced showing the value of the stethometer used in these inquiries, both in physiological studies and in medical practice.

III. "On Linear Differential Equations."—No. VI. By W. H. L. Russell, F.R.S. Received July 30, 1872.

We now consider linear differential equations which are satisfied by the roots of an algebraical equation admitting of explicit solution. To determine in what cases the linear differential equation

$$P\frac{d^n y}{dx^n}+Q\frac{d^{n-1}y}{dx^{n-1}}+\ldots+Ry=0$$

is satisfied by assuming

$$y=\sqrt[m]{X+\sqrt[r]{Y}+\sqrt[s]{Z}+\ldots}$$

when X, Y, Z are rational functions of (x). We shall commence by